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Physiological and morphological responses of grafted and nongrafted Italia grapevines to different annual shoot (Cane) positioning systems

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Abstract

Grapevines require timely and proper grafting, pruning, training, topping, pinching, girdling, and thinning techniques, even under optimal growing conditions. Accurate training and annual shoot positioning are particularly important for viticulture under protected cultivation, which is one of the most effective methods for sustainable grape production amid environmental stressors. A comparative study was conducted on vertical and horizontal cane positioning systems, focusing on the physiological and developmental responses of grafted and non-grafted Italia grapevines. The results indicated that bud burst percentages were higher in the vertical annual shoot positioning system compared to the horizontal type, with variations depending on the rootstock effects. The number of clusters per summer shoot was significantly influenced by the annual shoot positioning, with higher values observed in the vertical system. Pruning residue weight showed similar trends to the cluster number, except in non-grafted vines. Conversely, stomatal conductance was higher in the horizontal annual shoot positioning system than in the vertical type. In summary, annual shoot positioning systems significantly modulate the physiology and development of Italia grapevines, with effects varying based on rootstock use.

Keywords: Grapevine training, Protected cultivation, Sustainable viticulture, Vegetative growth, Vine physiology.

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Contents

Contribution of this paper to the literature

Increasing agricultural productivity under the pressures of climate change is a significant challenge in the 21st century. Precision canopy management of the plants is a key practice for agricultural efficiency. The present study is anticipated to guide viticulturists in sustainable grape growing in protected areas as well as urban agriculture.

1. Introduction

Grape cultivars belonging to *Vitis vinifera* L. have acquired significant economic value throughout history worldwide. Certain species, such as *Vitis berlandieri*, *V. riparia*, and *V. rupestris*, have been utilized to develop pest- and disease-resistant rootstocks. Thousands of grape cultivars classified as *Vitis vinifera* L. subsp. *sativa* are commonly cultivated for fresh consumption, raisins (dried berries), juice, and wine [1]. However, multidisciplinary studies emphasize that extreme climatic events, such as high temperatures, heavy rains, and global water scarcity, are forecasted to increase over time [2]. Therefore, grape production in soilless culture under protected agricultural structures (screens, greenhouses, or glasshouses) has been developed to increase agricultural output and quality by implementing modern agricultural techniques, even in challenging ecological conditions [3]. In addition, soilless culture can discard problems emerging from the soil, such as pests and diseases, high lime content, poor soil fertility, and salinity [4] and ensure high yield and quality [5]. Accurately established soilless culture enables viticulturists to utilize protected areas more efficiently through intensified production practices, such as proper vine canopy management systems (training/trellising), to achieve higher income per unit area. For the economically sustainable employment of soilless viticulture, researchers have recommended cultivating internationally popular grape cultivars [3]. For sustainable soilless viticulture, it is essential to thoroughly document vine physiology, vegetative development, bud fertility, phenology, agronomy, and the water and nutrient requirements of vines through experimental research. This is particularly important because grape cultivars exhibit varying degrees of suitability for soilless cultivation due to the extensive genetic diversity among *Vitis* genotypes. Establishing a well-balanced relationship between vegetative and reproductive growth is crucial for achieving high yields and quality over many years in soilless viticulture systems [6]. Position of the annual shoots affects the leaf sun and air exposure, vine physiology such as photosynthesis and transpiration, and resistance to pests and diseases [7, 8]. However, literature investigations yielded limited scientific knowledge on table grape production in soilless culture except for a few recent studies [3, 9]. Therefore, the present study was conducted to compare vertical and horizontal positioning systems of annual shoots for soilless culture for the first time, to our knowledge, regarding the physiological, developmental, and fruitfulness responses of Italia, an internationally popular table grape cultivar.

2. Materials and Methods

2.1. Experimental Design

This research was conducted to compare different annual shoot positioning systems for soilless cultivation of grapes, aiming for more efficient use of limited protected areas in urban farms and soilless agriculture at the research and implementation glasshouse (38°01.814'N, 032°30.546'E, 1158m above sea level) of Selçuk University, Turkey. The study focused on the cultivation of the Italia cultivar, a popular table grape variety extensively grown in Europe and Turkey. Four-year-old vines, both grafted and ungrafted (using rootstocks 99 R (*Vitis berlandieri* × *V. rupestris*), 5 BB (*V. berlandieri* × *V. riparia*), and 110 R (*V. berlandieri* × *V. rupestris*)), were individually cultivated in approximately 70-liter pots (35 cm diameter, 35 cm height). These pots contained a soilless medium substrate mixture of sterile peat (with 1.034% nitrogen, 0.94% P_2O_5, 0.64% K_2O; supplied by Klassman® (Klasmann-Deilmann GmbH, Geeste, Lower Saxony, Germany)) and perlite (0–3 mm in diameter) in equal volumes. The vines were arranged on concrete ground in an east–west orientation with spacing of 0.7×1.0 meters. Drip irrigation was employed, with one line per vine row equipped with a single emitter delivering 4 liters per hour per vine. Tap water with an approximate pH of 7.5 was used for irrigation. At the start of the study, nine uniformly grown vines per training treatment were labeled. Just before bud break in early spring, the vines were spur pruned, leaving three spurs per arm with two buds each, considering the genetic potential for fruitfulness of the basal winter buds on the canes of the Italia cultivar. During early summer, two canes approximately 0.5 meters in height (annual woody shoots) per vine, each with five buds, were positioned either vertically using supporting wires or horizontally from the arms to the rightward position on the supporting wires.

2.2. Measurements and Analyses

Physiological and developmental analyses were conducted two years after the establishment of the annual shoot (cane) positioning systems. To determine winter bud fertility (fruitfulness), the total number of buds remaining on each vine after pruning was counted. The bud burst, defined as the number of bursting winter buds on the cane, was periodically recorded during early spring, and the bud burst percentages were calculated. Bud burst was identified as the stage at which green tissue was visibly present beneath the bud scales [10]. Following the bud break and the subsequent two-month summer shoot elongation period, the number of clusters per summer shoot was recorded. The physiological response of grapevine leaves to different annual shoot positioning systems was investigated during the mid-summer season by measuring stomatal conductance (gs) and leaf temperature (T_{leaf}). The gs of the leaves was measured using the 5th or 6th leaf from the tip of the vine shoot, between 09:30 and 11:30 hours. Fully expanded, sun-exposed healthy leaves from the outer canopy were selected for both gs and T_{leaf} measurements [11]. The gs was measured near the central vein of the leaf blade [12] with a steady state porometer (SC-1 Leaf Porometer) [13] and was defined as mmol H_2O m^{-2} s^{-1}. The same lobes at the blade for all leaves were used to place the porometer sensor [14] since the gs may be different over such a large leaf. T_{leaf}). Was also recorded simultaneously with the gs measurements. The vine growth level was determined with fresh dormant pruning biomass residue weight obtained by weighing the pruning waste biomass of each vine in the physiological dormancy stage after the study season [9].

2.3. Statistical Analysis

The collected data were subjected to statistical analysis. Statistical tests were performed at $p<0.05$ using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA), using the least significant difference (LSD) test. Shoot positioning systems were statistically compared separately for each grafted and nongrafted grapevine.

3. Results and Discussion

Bud burst (bud break) significantly changed in Italia/99 R and Italia/110 R grapevines in response to different annual shoot positioning systems, while own-rooted Italia and Italia/5 BB vines did not show significant changes (Figure 1). Vertical annual shoot positioning resulted in higher gs than horizontal positioning across the grapevines at varying levels of statistical significance. Bud burst percentages were 20.0% and 12.8% higher in vertical positioning compared to horizontal for Italia/110 R and Italia/99 R, respectively. Rootstocks also caused notable variations in bud burst, with clear increases compared to own-rooted Italia vines. As indicated in previous studies, the fruitfulness of nodes on canes is influenced by both the cane positioning and the location of the node on the annual shoot [15]. Studies on canopy management and shoot positioning have demonstrated that temperature and the amount of light influence the number of bud bursts [16-18]. The overall bud burst percentage values across the vines are comparable with the findings of a previous study reported by Mohamed et al. [19], who studied Tunisian vineyards established using Crimson Seedless grapes observed that the bud break percentages recorded for different annual shoot positioning systems in soilless-grown grapevines could be acceptable for economically efficient grape production. This similarity suggests that the methods employed may be viable for optimizing yield and cost-effectiveness in grape cultivation.

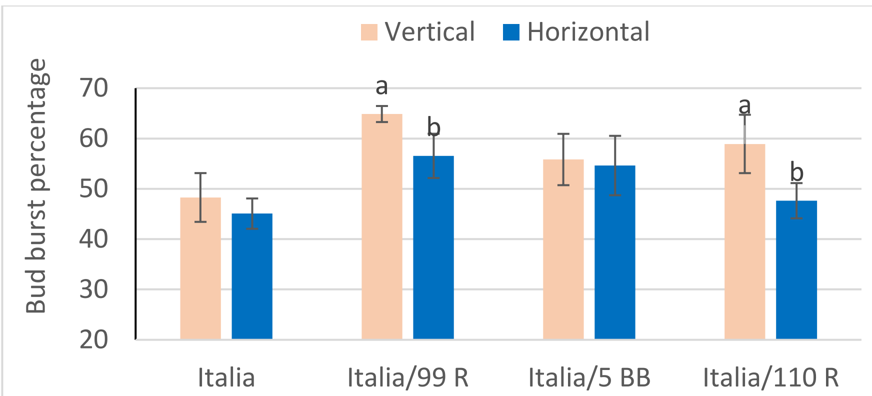

Figure 1. Differences in bud break percentages (%) of grafted and nongrafted Italia grapevines in response to different annual shoot positioning systems.

Note: Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

Cluster number per summer shoot, indicating bud fertility, significantly varied among the vines in response to shoot positioning systems (Figure 2). The cluster numbers per annual shoot were significantly higher in vertical positioning than in horizontal positioning across the vines. The greatest difference in cluster numbers per annual shoot was observed in Italia/5 BB vines (61.9%), followed by Italia/99 R (57.4%), while the least difference was recorded in Italia/110 R (23.1%). Studies have revealed that bud fertility in grapevines depends on the cultivar and rootstock, the type of bud, and its position along the cane (annual shoot). Additionally, ecological conditions such as temperature, light, water availability, nutrient availability, vine carbohydrate reserves, and hormonal balance influence bud fertility and overall vine productivity [20]. Cultivation practices can further modulate bud fruitfulness in grapevines [21]. The annual shoot positioning systems practiced in the study obviously affected the fruitfulness of Italia vines depending on the rootstocks used.

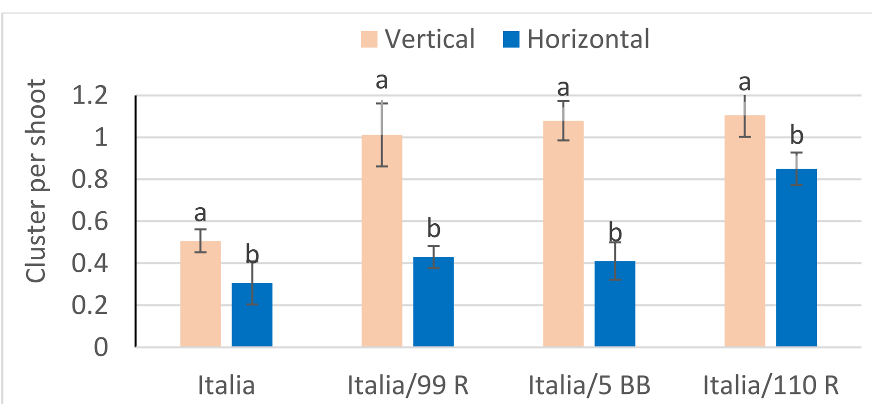

Figure 2. Differences in cluster number per annual shoot (Number) of grafted and nongrafted Italia grapevines in response to different shoot positioning systems.

Note: Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

Annual shoot positioning systems significantly affected the stomatal conductance (gs) regardless of the rootstock used across the vines (Figure 3). The gs was consistently higher in horizontally positioned annual shoots compared to those with vertical positioning. The most notable change was observed in Italia/110 R, with a 38.4% increase (from 201.9 to 279.4 mmol H_2O m^{-2} s^{-1}) for vertical and horizontal positioning, respectively. Additionally, there were 21.7% and 20.7% increases in gs for Italia/5 BB and Italia/99 R vines, respectively, when comparing vertical to horizontal shoot positioning. Previous studies have confirmed that leaf orientation directly influences leaf sun and air exposure, which in turn affects physiological responses such as gs. Therefore, leaf positioning plays a crucial role in modulating these physiological parameters, impacting overall vine health and productivity [7, 8]. In the present study, annual shoot positioning and rootstock use significantly affected the growth status of Italia vines. The overall gs values were similar to those of Karadere et al. [9], who studied the physiological, developmental, and agronomic responses of three different table grape cultivars to various training systems in soilless culture.

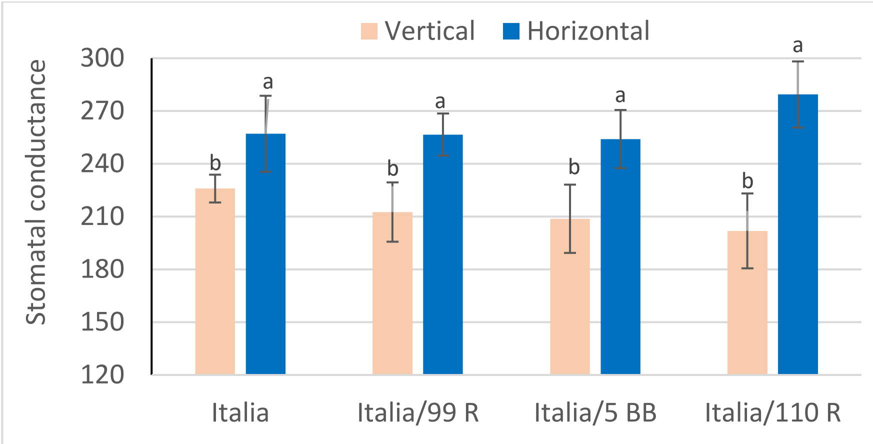

Figure 3. Differences in stomatal conductance (mmol $H_2Om^{-2}\ s^{-1}$) of grafted and nongrafted Italia grapevines in response to different annual shoot positioning systems.

Note: Values of bars indicated by different letters identify significantly different means (P < 0.05, LSD).

The $_{leaf}$ temperature showed significant variation among the Italia (own rooted) and Italia/99 R vines in response to annual shoot positioning systems, although there were no significant differences for the vines grafted on 5 BB or 110 R (Figure 4). The $_{leaf}$ temperatures were significantly higher in vertically positioned annual shoots than in horizontally positioned shoots for Italia and Italia/99 R vines, with 2.8% and 4.2% differences among the positioning systems. The $_{leaf}$ temperatures are similar to those recorded by researchers studying the $_{leaf}$ temperatures of grapevine cultivars such as Alphonse Lavallée, Crimson Seedless, and Italia, with an emphasis on daily climatic responses. Overall, the $_{leaf}$ temperatures were slightly higher than the threshold values recommended by Greer [22] for optimal photosynthesis (25–30°C) in grapevines, although the $_{leaf}$ temperature for horizontally positioned Italia/99 R vines was approaching the upper limit of the optimal range. As previously reported by Marguerit et al. [23], the $_{leaf}$ temperature of grapevines is directly affected by the rootstock. Therefore, differences in $_{leaf}$ temperature among the vines may arise from the combined effects of annual shoot positioning and rootstocks on transpiration rates and the cooling of the scion leaves.

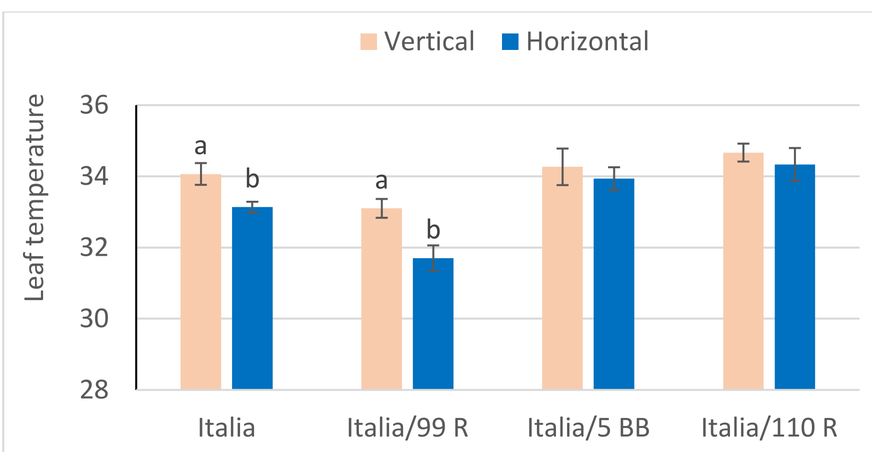

Figure 4. Differences in leaf temperature (^{0}C) of grafted and nongrafted Italia grapevines in response to different annual shoot positioning systems.

Note: Values of bars indicated by different letters identify significantly different means (P < 0.05, LSD).

Annual shoot positioning systems significantly affected the pruning residue weight of grafted vines, while there was no significant difference for non-grafted vines in response to shoot positioning (Figure 5). The pruning residue weights were higher in vertically positioned annual shoots than in those with horizontal positioning in grafted vines. The greatest change was recorded in Italia/110 R (42.9%, from 130.3 to 74.3 g) for vertical and horizontal positioning, respectively. Additionally, there were 38.7% and 31.4% changes in the pruning residue weight of Italia/99 R and Italia/5 BB vines when comparing vertical to horizontal shoot positioning. The reduction in shoot growth in the horizontal position might result from smaller xylem vessel formation in the secondary xylem, possibly due to an increase in auxin concentration at the apex and the proximal shoot portions [24]. This change ultimately decreases sap flow, reduces hydraulic conductivity, and lowers the stomatal conductance (gs) to the leaves [25]. Nonetheless, dormant cane pruning residue weight may not be a fully concrete indicator of vine vegetative development, as distal vegetative growth was modified by hedging and skirting [15]. Different canopy management practices, such as annual shoot positioning, may obscure differences in vine vegetative development. It should also be emphasized that excessive vegetative development is not desirable for sustainable grape production, as it can lead to certain physiological and agronomic problems.

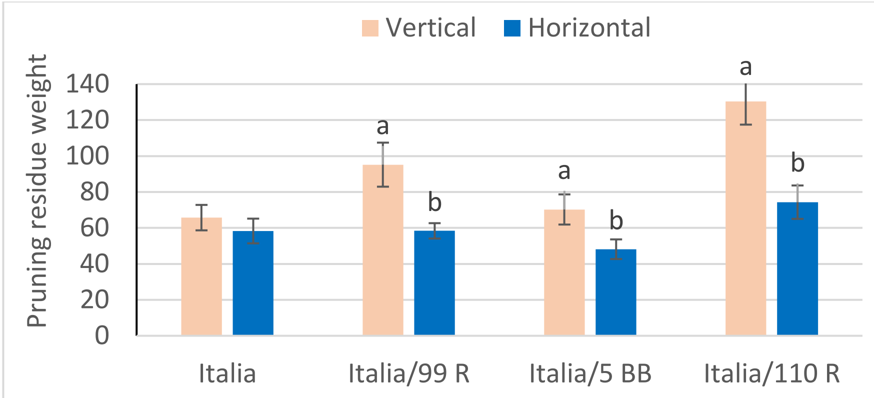

Figure 5. Differences in pruning residue weight (g) of grafted and nongrafted Italia grapevines in response to different annual shoot positioning systems.

Note: Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

4. Conclusion

In the present study, physiological and developmental responses of grafted and nongrafted Italia grapevines to vertical and horizontal cane positioning systems were comparatively investigated. The vertical annual shoot positioning system resulted in higher bud burst percentages compared to the horizontal type, depending on the effects of the rootstock. The number of clusters per summer shoot and the weight of pruning residues were consistently higher in the vertical positioning of annual shoots than in the horizontal type. Conversely, stomatal conductance was higher in the horizontal annual shoot positioning than in the vertical type. Overall, annual shoot positioning systems influenced the physiology and development of Italia vines under the effects of different rootstocks. Viticulturists should consider various factors, such as the bud fruitfulness attributes of genotypes and the efficient use of limited production areas, when deciding on training systems to implement.

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